

FERMI AT LOS ALAMOS AND THE EARLY BRITAIN'S WAY TO NUCLEAR ENERGY

S. ESPOSITO

ABSTRACT. A novel recovery of some important documents related to the Fermi course on neutron physics, held at Los Alamos in 1945, is announced. Its relevance for the effective launch of a British nuclear programme in the early postwar period, independently of the U.S. technical cooperation (precluded by the American authorities) and warmly supported by Chadwick, is discussed.

The first achievements leading to the exploitation of the enormous amount of the energy trapped inside the atom have been, as for all scientific achievements, just part of the search of science for a fuller explanation of Nature and the world around us. Quite differently from other cases, however, the world realized abruptly of the power of nuclear energy as early as August 1945, with the well-known events that led to the end of the second world war. Once the facts demonstrated that some correct knowledge was reached on that part of Nature's functioning, time came for the scientist, even for the ones who contributed to those achievements, to pause and reason a bit more on the results obtained.

As far as we know, the first occasion for this was the course on neutron physics that Enrico Fermi taught at Los Alamos in the fall of 1945 [1]. The teacher and the students (about thirty) of such a course, in fact, were some of the people who themselves contributed, with different tasks, to the Manhattan Project or other similar projects. Unfortunately enough, for some time only the attending students benefitted from the teaching of Fermi, ranging over more than ten years of important discoveries, since the circulation of the notes taken down in class was limited by presumed secrecy reasons.

The secrecy affair dates back to 1939, just after the discovery of nuclear fission by Otto Hahn and Fritz Strassmann in Germany, and to this regard the words of Fermi himself are illuminating:

A world war was about to start. The new possibilities [opened by the discovery of the fission of the uranium atom] appeared likely to be important, not only for peace but also for war.

A group of physicists in the United States – including Leo Szilard, Walter Zinn, Herbert Anderson, and myself – agreed privately to delay further publications of the findings in this field.

We were afraid these finding might help the Nazis.

Our action, of course, represented a break with the scientific tradition and was not taken lightly. Subsequently, when the government became interested in the atom bomb project, secrecy became compulsory. [...]

Secrecy that we thought was an unwelcome necessity of the war still appears to be an unwelcome necessity. [2]

The “unwelcome necessity” was formally revealed by scientists of the Chicago branch of the Manhattan Project as early as June 1945 in the *Franck Report*: “Nuclear bombs cannot possibly remain a ‘secret weapon’ at the exclusive disposal of this country for more than a few years. The scientific facts on which construction is based are well known to scientists of other countries” [3].

The expectations of these scientists, for removing the wartime secrecy and restoring nuclear science to the realm of open scientific inquiry, came together in the McMahon Bill of December 1945. The intent was, indeed, “the free dissemination of basic scientific information,” “as freely as may be consistent with the foreign and domestic policies” [3] However the final act, approved by the American Congress and signed by the President on August 1946 as the Atomic Energy Act, changed the original vision, and became “a program for the control of scientific and technical information.”

A Declassification Guide regarding, among the others, papers dealing with the pile theory and the theory of neutron diffusion was issued as early as 30 March 1946, and the subjects were discussed in several meeting of the Basic Responsible Reviewers of the Atomic Energy Commission (A.E.C.).¹ Some of the papers first released by the Declassification Office, which served also as a guide for declassification of further papers on the same subject, were the following (see the mentioned letter by Batson): the first eight chapter of *Neutron Physics*, the lecture course by Fermi (notes written by I. Halpern), the papers *Elementary Theory of the Pile* by E. Fermi, *Elementary Pile Theory* by S.K. Allison and *Theoretical Discussion of a Small Homogeneous and Enriched Detector* by R.F. Christy. Indeed, the scientific community first knew about the detailed general functioning of an atomic pile from the Fermi’s paper mentioned just above, which was published in *Science* in 1947 [4].

A first part of the Fermi lectures at Los Alamos, containing neutron physics without reference to chain reactions, was in fact declassified on 5 September 1946, while the remaining part has been declassified only in 1962. Both parts have been later published in the *Collected Papers* by Fermi [1]. Leaving aside the pregnant didactic style by Fermi, the main relevance of such notes is that they present, for the first time, a complete and accurate treatment of neutron physics from its beginning, including a detailed study of the physics of the atomic piles. In this respect it is not surprising that especially the second part of the notes, dealing just with chain reactions and pile physics, was considered as “confidential” material by governmental offices.

Nevertheless, something happened that eluded the control network for such information.

We have, in fact, recently recovered a *different* version of the Fermi lectures at Los Alamos, formerly belonged to James Chadwick and now deposited at the Churchill Archive Centre in Cambridge (U.K.). The folders relevant to us are essentially two. The first one (CHAD I 17/3) contains a letter from the A.E.C., already mentioned above, a copy of the paper *Elementary Theory of the Pile* by Fermi² and a copy of

¹See a letter by Richard T. Batson conserved among the Chadwick papers at the Churchill Archive Centre, Cambridge (U.K.), in the folder CHAD I 17/3; see below.

²This paper is reproduced in Ref. [1]; in particular see page 538 of the second volume.

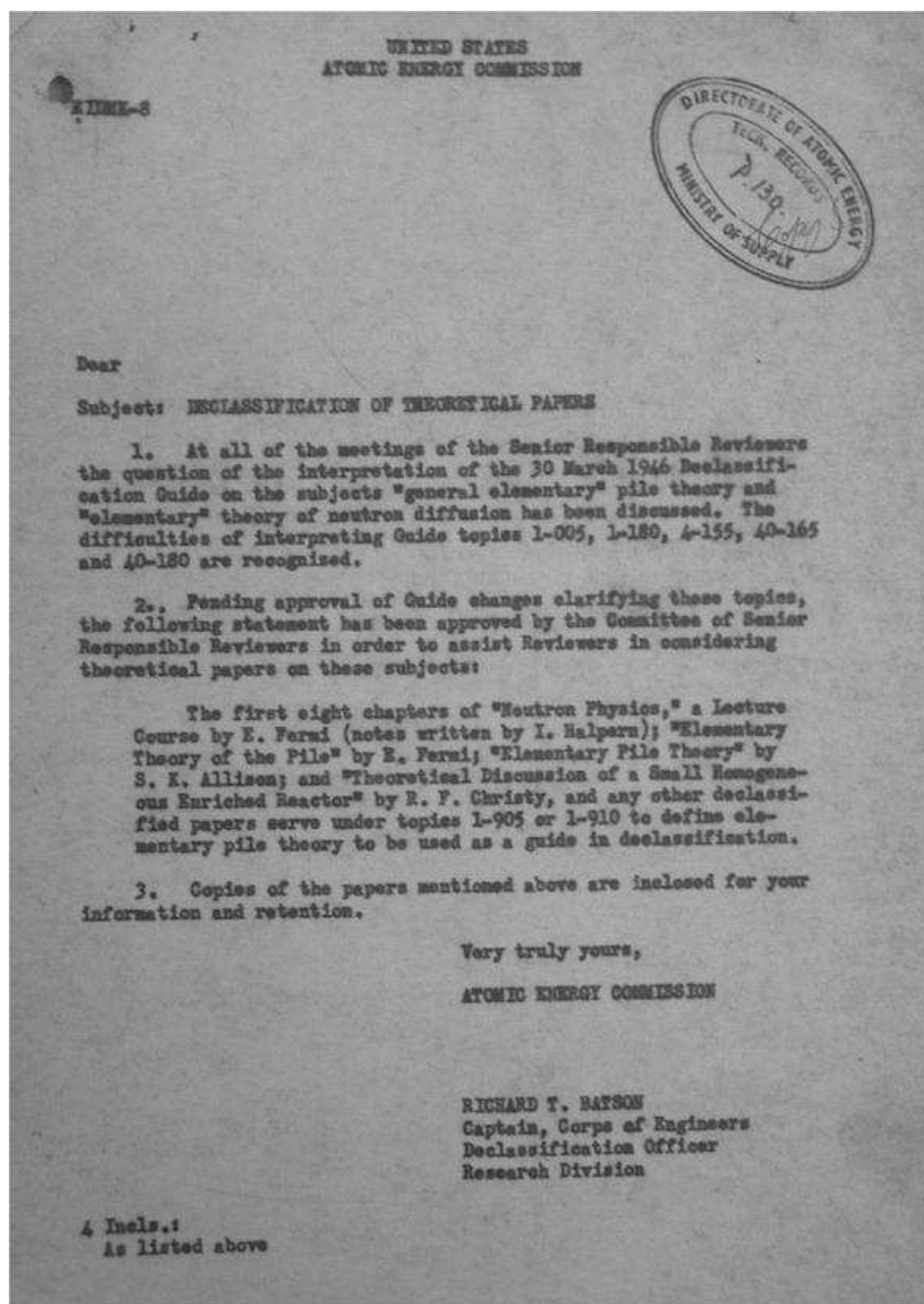


FIGURE 1. The letter from Richard T. Batson conserved among the Chadwick's papers, regarding the declassification of several documents about nuclear studies. (Courtesy of the Churchill Archive Centre, Cambridge).

only the *first part* of the Halpern notes of the Fermi lectures. Instead the second folder (CHAD I 4/1) contains a version of the *complete* set of lectures made by A.P. French, dated June 23, 1947.

It is probably not strange³ that the material of the first folder belonged to Chadwick, since he was the respected (also by Americans) leader of the British Mission in the United States.

The British Mission was formed after the Quebec Agreement on Anglo-American collaboration was signed jointly by W. Churchill and F.D. Roosevelt. Almost all the work carried out in Great Britain on ^{235}U and atomic bomb calculations was suspended, and a number of British scientists headed by Chadwick were transferred to the United States. They joined to work in different parts of the American programme for the nuclear energy, but the biggest part of the British contingent was at Los Alamos, and Chadwick himself was later present at the world's first nuclear test at Alamogordo on 16 July 1945.

Several scientists of the British Mission were very young and, among the others, it was Anthony P. French who graduated in Physics at the Cambridge University just in 1942. In the same year he joined the atomic bomb project ("Tube Alloys") at the Cavendish Laboratory, and was later sent to Los Alamos in October 1944 as a member of the British Mission. Here he worked with E. Bretscher, O.R. Frisch, J. Hughes, D.G. Marshall, P.B. Moon, M.J. Poole, J. Rotblat, E.W. Titterton and J.L. Tuck in the field of experimental nuclear physics [5],⁴ and returned to the United Kingdom in 1946, working for two years at the just newly formed Atomic Energy Research Establishment (A.E.R.E.). The second folder of the Chadwick papers mentioned above contains just the notes of Fermi course on neutron physics taken by French on his own, when he was at Los Alamos, and later (1947) re-organized into a final version when he came back to England.

A preliminary study shows that the French notes do *not* depend on the Halpern ones, but French probably saw them (the organization of the introduction is similar). The topics covered are exactly the same, although to a certain extent the material is organized in a little different manner, but the text of the notes is different in the two versions. In few cases, however, similar or even identical words or sentences are present in both versions, likely denoting quotes from an original wording by Fermi. In general, the French notes are much more detailed (and accurate), with a great number of shorter or larger peculiar additions⁵ (explanations, calculations, data or other, and 5 more exercises) not present in the Halpern notes: at least 15 of these additions are quite relevant. Instead the peculiar additions present in the Halpern version but not in the French one are very few (including 3 more exercises), only one of them being relevant. Also, the French paper contains

³Note however that only a typed copy of the letter from A.E.C., without the name of the addressee and unsigned, is present in the folder, while it contains no copy of the papers by Allison and Christy mentioned above (the letter explicitly refers to them and to the Fermi papers).

⁴The remaining part of the British Mission was composed by B. Davison, K. Fuchs, D.J. Littler, W.G. Marley, R.E. Peierls, W.G. Penney, G. Placzek, H. Sheard and T.H.R. Skyrmes.

⁵Our preliminary study has shown that the case is completely different, for example, from that of the revision of the (first part of the) Halpern notes made by J.G. Beckerley in 1951 (document AECD 2664 of the Atomic Energy Commission). Here the author *re-wrote* the Fermi lectures by including several additions from *other* sources, "where clarity demanded more information and where the addition of recent data made the text more complete." Contrarily to the present case (as it is evident from the text of the notes), Beckerley "was not privileged to attend the course" by Fermi.

the six questions which were set as a final examination at the end of the lecture course.

It is quite interesting that the greater detail already present in the French notes increases even more in quality (especially figures and data) in the last part, directly related to chain reactions and their applications, and, moreover, explicit references to bomb applications are made.

Finally, regarding Fermi's involvement in his own delivery of the lectures, differently from Halpern, French limits the subjects treated by R.F. Christy and E. Segrè (while Fermi was absent) to the scattering of neutrons and the albedo in the reflection of neutrons, respectively.

The relevance of the present recovery is, therefore, clearly twofold.

On a purely "scientific" side, it is now evident that our previous knowledge of the Fermi course was incomplete and, to some extent (limited to the Halpern notes) misleading. As his usual, Fermi was very accurate in the choice of the topics, that he developed in detail and in a very clear manner, a peculiarity which does not often emerge from the notes taken directly down in class by students, and later arranged into the Halpern version. Further studies on the original material present only in the French notes are currently carrying out, and will probably reveal some other precious results which will be of interest to historians of physics (and to teachers of nuclear physics).

Instead we here dwell a bit more on the "historical" relevance of the present recovery of the French notes.

As it is clear from what reported above, despite the classification of the second part of the Fermi lectures by the U.S. authorities, the detailed lectures on chain reactions and pile physics (including applications to the bomb) were extensively known to Chadwick, and thus to several British nuclear physicists, as early as in 1947.

This is quite remarkable if compared with the persuasion of some British people who believed that the U.S. authorities wanted a postwar American nuclear monopoly. A decisive confirmation of this view came, in fact, with the approval of the final version of the McMahon Act, as already mentioned, which made illegal the passing of "restricted data" to any foreign country, *including* the United Kingdom. The seriousness of the consequences of the McMahon Act for Anglo-American collaboration was readily recognized by Chadwick [6], whose warning proved correct very soon, since until 1948 no technical cooperation at all was set up and until 1955 it was extremely limited. On the other hand, Chadwick was a valiant supporter of a Britain's own nuclear project, mainly directed towards the production in the United Kingdom of atomic bombs and plants for producing fissile material, but also devoted to possible medical applications. However, after the American legislation on the control of nuclear energy was issued, British scientists were (rightly) discouraged about the realization of a Britain's own project without American technological cooperation, since it appeared clear to them that key knowledge in this field was then accumulated only in the United States. In this respect, Chadwick's remark was again crucial: "Are we so helpless," he would ask, "that we can do nothing without the U.S.?" [7].

The making of the French notes goes just in this direction and, although no direct realization can at the moment be established, in a sense it seems to support Chadwick's optimistic view. And this is particularly intriguing, if his anxiety in

(99)

Chapter 17.Fast Reactors.Elementary Considerations.

We have discussed the mechanism of thermal neutron chain reactions. The question now arises how to produce a nuclear explosion. In Chapter 15 we have seen (equation at top of p. 96) that the growth of neutron density is given by

$$n(t) = n(0) \cdot \exp \left[\frac{\lambda}{\Lambda} e^{-\omega t} (k - k_0) \cdot t \right]. \quad \text{We can put}$$

$e^{-\omega t} \sim 1$, and then the e -folding time ($=$ time for neutron population to increase by a factor e) is

$$\frac{\Lambda}{v \cdot (k - k_0)}. \quad \text{For a thermal pile } \frac{\Lambda}{v} \sim 10^{-5} \text{ sec. and}$$

$(k - k_0) \sim 0.1$. Thus the e -folding time is $\sim 10^{-2}$ sec. or more. In the water boiler (p. 98) $\Lambda \sim 50$ cm., $v \sim 10^5$ cm/sec and $k \sim 2$, giving an e -folding time of $\sim 10^{-4}$ sec. For a fast reactor, of U^{235} or Pu , $\Lambda \sim 10$ cm, $v \sim 10^9$ cm/sec. and $k \sim 2$, giving an e -folding time of $\sim 10^{-8}$ sec. These times are all minima, corresponding to the most rapid possible growths.

In 1 kilogram of fissionable material there are $2 \cdot 10^{24}$ atoms, approximately. If we denote the reciprocal of the e -folding time by α , the reaction could continue for at most t seconds, where

$$10^{24} = e^{\alpha t}. \quad \text{This gives the following values of } t:$$

Graphite pile	0.5 sec.
Water boiler	0.005 sec.
Fast reactor	0.5 microsec.

In practice,

mechanical effects begin 5 or so generations before the end; the energy release causes pressures which expand the reactor. Eventually expansion and leakage make the assembly sub-critical. The time-dependence of the process is indicated in Fig. 78.

Let us suppose that the pressure goes as

$$P(t) = P_0 \cdot e^{\alpha t},$$

and let us suppose also that the reactor is spherical. Then essentially the process of expansion consists in the outward acceleration

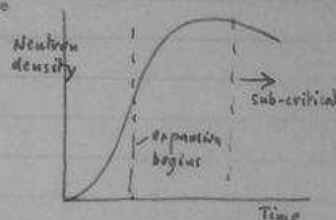


Fig. 78.

FIGURE 2. One page excerpted from the French version of the Fermi lecture notes on neutron physics. Note the explicit reference to a nuclear explosion in the second line of the text. (Courtesy of the Churchill Archive Centre, Cambridge).

avoiding anything which might suggest to the Americans that the British were trying to pry out secret information [6] is taken into account.

As a matter of fact, the British programme for nuclear energy, initiated in the early postwar period, proved remarkably successful. This was certainly due to the ability of British scientists under the sensible guidance of Chadwick, but the French notes of the Fermi course at Los Alamos proved to be at least very useful in the effective launch of the British programme, and the role played by Chadwick also to this regard was crucial.

Some previously obscure points on this matter are now seemingly made clearer, and further studies even in this direction will led to potentially interesting new results.

Acknowledgments. The active and valuable cooperation of the staff of the Churchill Archive Centre, Cambridge (U.K.) and of the Information Resource Centre of the U.S. Embassy in Rome is here gratefully acknowledged. The author is also indebted to G. Miele for his kind support and encouragement.

REFERENCES

- [1] E. Fermi, *Collected Papers*, edited by E. Amaldi *et al.*, University of Chicago Press - Accademia Nazionale dei Lincei, Chicago - Rome, 1962-1965, 2 volumes (1962). See, in particular, the introduction to the Fermi course at page 437ff of the second volume.
- [2] E. Fermi, Chicago Sun Times, November 23, 1952. This paper is practically unknown, since it is not included in the list of collected papers in Ref. [1].
- [3] See, for example, H. Morland, *Cardozo Law Review* **26** (2005) 1401-8.
- [4] E. Fermi, *Science* **105** (1947) 27-32.
- [5] F.M. Szasz, *British Scientists and the Manhattan Project: The Los Alamos Years*, Palgrave Macmillan, New York, 1992.
- [6] H. Massey and N. Feather, *Biographical Memoirs of Fellows of the Royal Society* **22** (1976) 10-70.
- [7] M. Gowing, *Notes and Records of the Royal Society of London* **47** (1993) 79-92.

S. Esposito: DIPARTIMENTO DI SCIENZE FISICHE, UNIVERSITÀ DI NAPOLI "FEDERICO II" & I.N.F.N. SEZIONE DI NAPOLI, COMPLESSO UNIVERSITARIO DI M. S. ANGELO, VIA CINTHIA, 80126 NAPOLI (Salvatore.Esposito@na.infn.it)